

The plasma wake downstream of lunar topographic obstacles: Preliminary Results from 2D Particle Simulations

M. I. Zimmerman^{1,2}, W. M. Farrell^{1,3}, T. J. Stubbs^{1,3,4}, J. S. Halekas^{3,5}, ¹NASA Goddard Space Flight Center, Greenbelt, MD, USA (michael.i.zimmerman@nasa.gov), ²Oak Ridge Associated Universities, Oak Ridge, TN, USA, ³NASA Lunar Science Institute, NASA Ames Research Center, Moffett Field, California, USA, ⁴Goddard Earth Sciences and Technology Center, University of Maryland Baltimore County, Baltimore, Maryland, USA, ⁵Space Sciences Laboratory, University of California, Berkeley, California, USA.

Summary

Anticipating the plasma and electrical environments in permanently shadowed regions (PSRs) of the moon is critical in understanding local processes of space weathering, surface charging, surface chemistry, volatile production and trapping, exo-ion sputtering, and charged dust transport. In the present study, we have employed the open-source XOOPIC code [1] to investigate the effects of solar wind conditions and plasma-surface interactions on the electrical environment in PSRs through fully two-dimensional particle-in-cell simulations.

By direct analogy with current understanding of the global lunar wake (e.g., references [2–5]) deep, near-terminator, shadowed craters are expected to produce plasma “mini-wakes” just leeward of the crater wall [6]. The present results (e.g., Figure 1) are in agreement with previous claims that hot electrons rush into the crater void ahead of the heavier ions, forming a negative cloud of charge. Charge separation along the initial plasma-vacuum interface gives rise to an ambipolar electric field that subsequently accelerates ions into the void.

However, the situation is complicated by the presence of the dynamic lunar surface, which develops an electric potential in response to local plasma currents (e.g., Figure 1a). In some regimes, wake structure is clearly affected by the presence of the charged crater floor as it seeks to achieve current balance (i.e. zero net current to the surface).

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References

- [1] J. P. Verboncoeur, A. B. Langdon, and N. T. Gladd. An object-oriented electromagnetic PIC code. *Computer Physics Communications*, 87:199–211, May 1995. doi: 10.1016/0010-4655(94)00173-Y.
- [2] J. E. Crow, P. L. Auer, and J. E. Allen. The expansion of a plasma into a vacuum. *Journal of Plasma Physics*, 14: 65–76, August 1975. doi: 10.1017/S0022377800025538.

- [3] W. M. Farrell, M. L. Kaiser, J. T. Steinberg, and S. D. Bale. A simple simulation of a plasma void: Applications to Wind observations of the lunar wake. *Journal of Geophysical Research*, 103:23653–23660, October 1998. doi: 10.1029/97JA03717.
- [4] W. M. Farrell, T. J. Stubbs, J. S. Halekas, G. T. Delory, M. R. Collier, R. R. Vondrak, and R. P. Lin. Loss of solar wind plasma neutrality and affect on surface potentials near the lunar terminator and shadowed polar regions. *Geophysical Research Letters*, 35:5105–+, March 2008. doi: 10.1029/2007GL032653.
- [5] J. S. Halekas, S. D. Bale, D. L. Mitchell, and R. P. Lin. Electrons and magnetic fields in the lunar plasma wake. *Journal of Geophysical Research (Space Physics)*, 110: 7222–+, July 2005. doi: 10.1029/2004JA010991.
- [6] W. M. Farrell, T. J. Stubbs, J. S. Halekas, R. M. Killen, G. T. Delory, M. R. Collier, and R. R. Vondrak. Anticipated electrical environment within permanently shadowed lunar craters. *Journal of Geophysical Research (Planets)*, 115: 3004–+, March 2010. doi: 10.1029/2009JE003464.

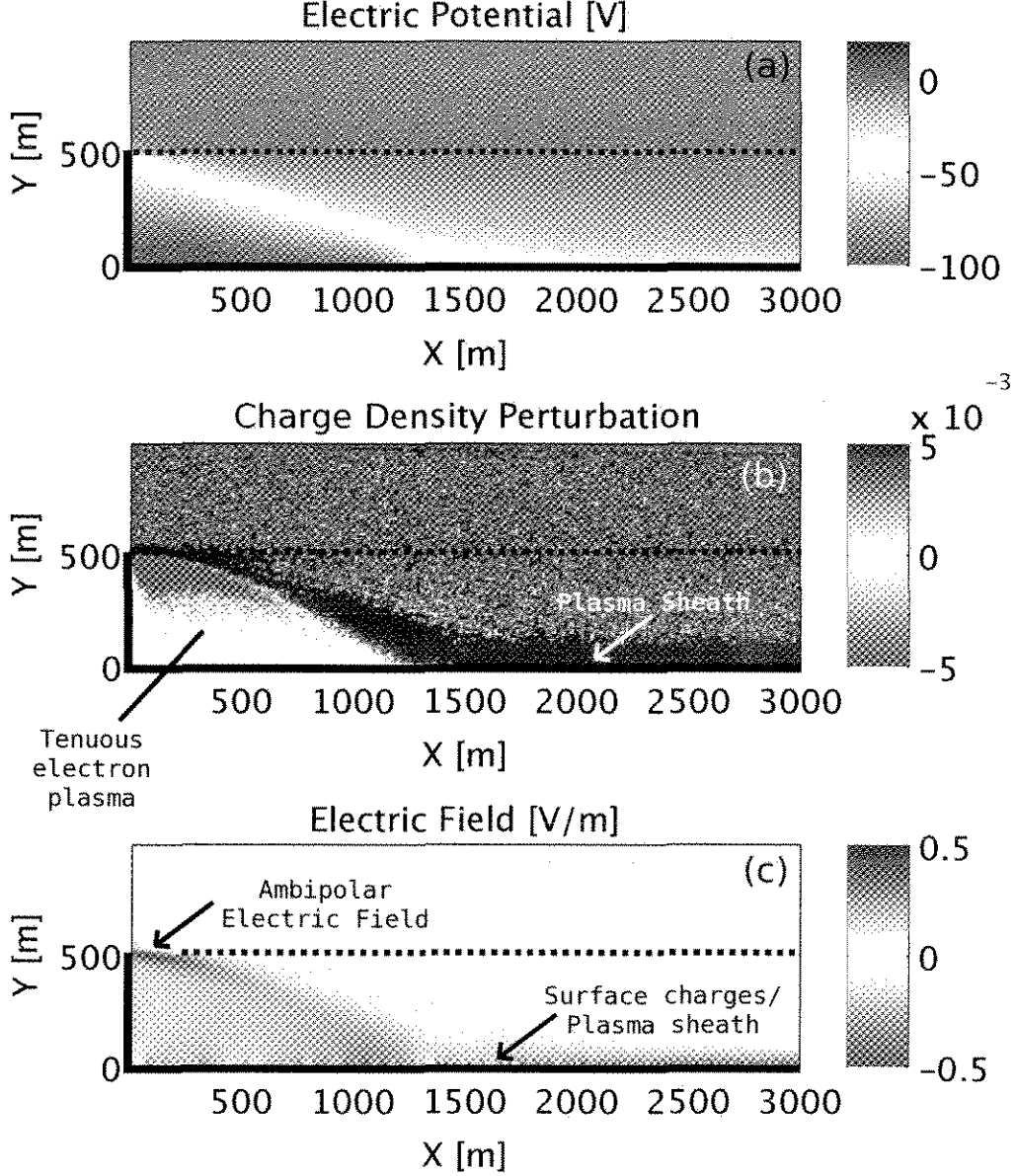


Figure 1: Fully 2D simulated plasma wake structure in a polar topographic depression. The lunar surface is denoted by a thick black line, and the initial plasma-vacuum interface is depicted as a dashed black line. Solar wind plasma flows from the left above a height of 500 m, with bulk plasma conditions $h_{crater}/\lambda_{De} \sim 50$, $v_{the}/v_{sw} \sim 5$, and $v_{thi}/v_{the} \sim \sqrt{m_e/m_i} \sim 0.02$, where $h_{crater} = 500$ m is the crater depth and $v_{sw} = 400$ km/s is the solar wind convection speed. Thermal electrons initially rush into the wake ahead of the more massive ions (panel b), forming an ambipolar electric field just leeward of the crater wall (panel c) that serves to accelerate ions into the void. Large negative electric potentials occur where only the most energetic electrons can escape the bulk solar wind plasma, and surfaces exposed only to electrons charge highly negative (panel a).